

# Comparison of MODTRAN and FASCODE for Selection of a Cirrus Cloud Detection Band Near the 1.38- $\mu$ m Water Absorption Window

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A handwritten signature in cursive script, reading "Michael Zambrana", written over a horizontal line.

Michael Zambrana  
SMC/AXE

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## 1. Introduction

The 1.375- $\mu\text{m}$  water vapor band has been chosen by MODIS and NPOESS as a cirrus cloud detection channel based on the work of Gao et al. (1993; 1995; 1998). The nominal band is centered at 1.375  $\mu\text{m}$  and is 0.03- $\mu\text{m}$  (30 nm) wide, i.e., 1.360–1.390  $\mu\text{m}$ . In this report, we analyze this detection approach and use the results to answer the question: Is MODTRAN resolution sufficient to fully characterize this detection approach or is the higher spectral resolution of FASCODE required?

Cirrus clouds, and especially thin cirrus, occur primarily in the upper troposphere. Gao's approach to detecting cirrus from space recognized that detecting cirrus is best done in an atmospheric water-vapor band that blocks most or all of the upwelling scattered sunlight from the surface. Figures 1 and 2 show the MODTRAN atmospheric transmission from space to sea level for the mid-latitude-summer (MLS) and sub-arctic-winter (SAW) atmospheres in the vicinity of the 1.375- $\mu\text{m}$  water-vapor absorption band. The central part of the band is virtually opaque for the MLS atmosphere, but there is a small average transmission (0.0567) for the SAW atmosphere over the MODIS band.

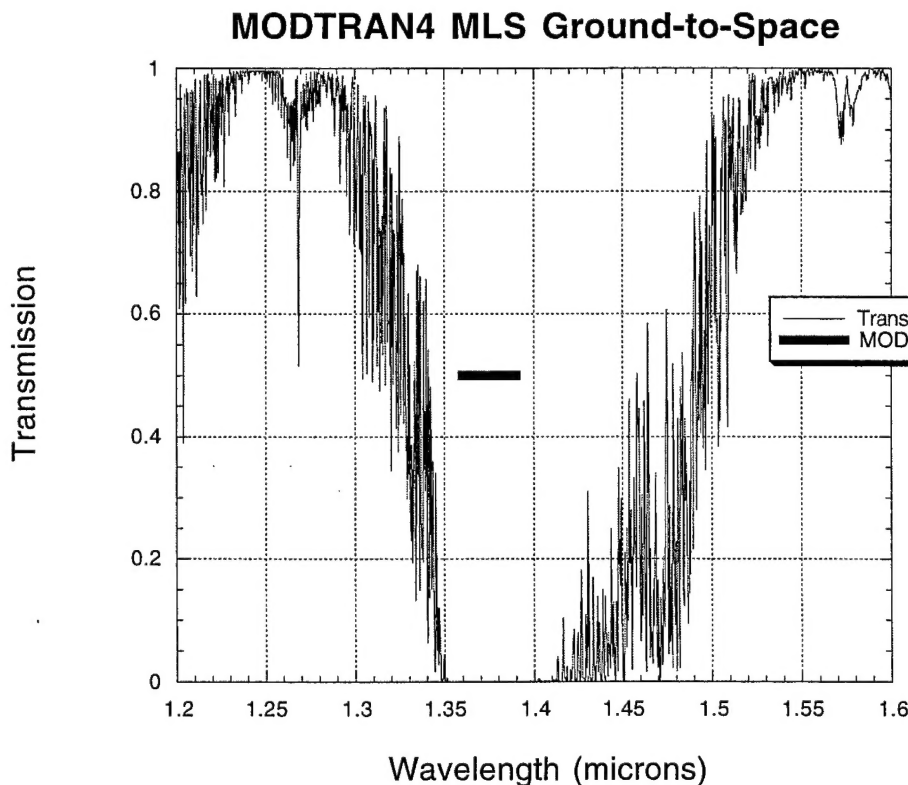


Figure 1. MODTRAN atmospheric transmission from space to sea level for a mid-latitude summer model atmosphere in the vicinity of the 1.375  $\mu\text{m}$  water-vapor absorption band. The central part of the band is virtually opaque. Also shown is the position of the nominal MODIS band.

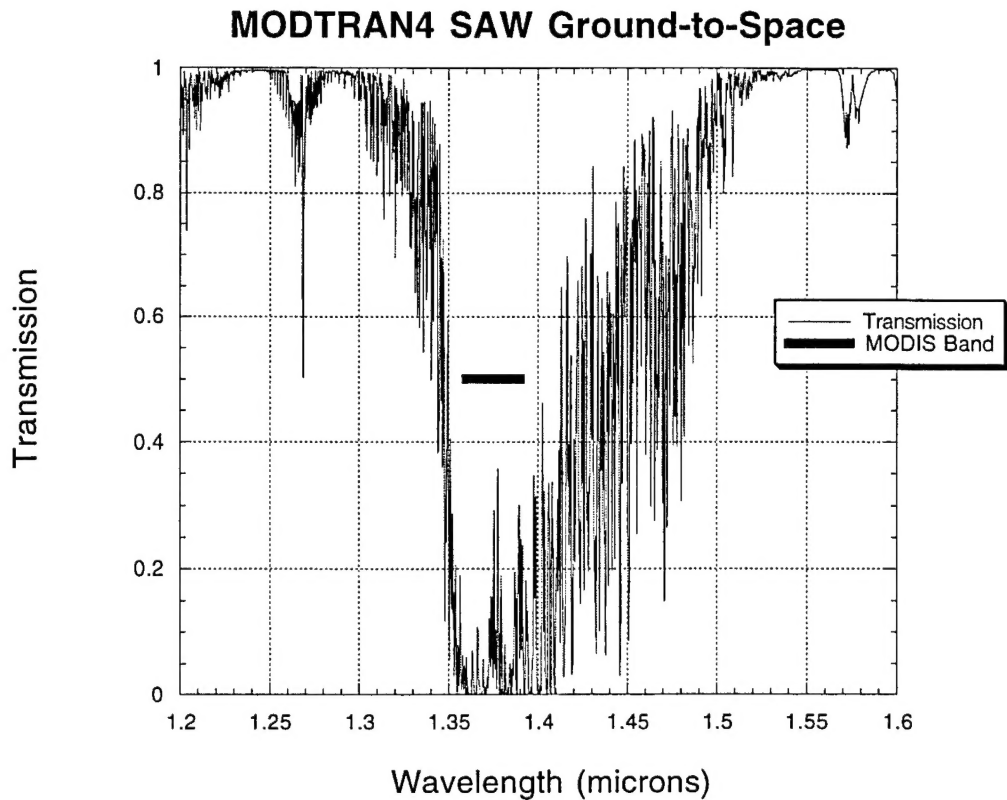


Figure 2. MODTRAN atmospheric transmission from space to sea level for a sub-arctic winter atmosphere in the vicinity of the 1.375  $\mu\text{m}$  water-vapor absorption band. The central part of the band has a small average transmission (0.0567). Also shown is the position of the nominal MODIS band.

In the vicinity of the 1.375- $\mu\text{m}$  water-vapor absorption band, the Earth appears very dark from space, and the only clouds that can be seen are those that are above most of the water vapor. These are usually cirrus but can also include volcanic aerosols and certain clouds associated with deep convection and thunderstorms, including anvil cirrus (incus). Gao and his collaborators chose a wavelength band for MODIS in the 1.375- $\mu\text{m}$  region for cirrus detection. Measurements and simulations proved this to be an effective way of detecting most cirrus. By setting a threshold radiance, a cirrus/no cirrus detection algorithm can determine whether cirrus is present, and by modeling how sunlight scatters from cirrus clouds some additional information about the composition of the cirrus themselves can also be retrieved.

## 2. Modeling

Gao's original work and his conclusions leading to the cirrus detection scheme were based on LOWTRAN7 (resolution  $20\text{ cm}^{-1}$ ) (Gao 1995). The LOWTRAN7 model is now considered obsolete, having been replaced by MODTRAN. By comparison, MODTRAN's resolution is  $2\text{ cm}^{-1}$  and FASCODE's is  $0.0002\text{ cm}^{-1}$ . Inverse centimeter ( $\text{cm}^{-1}$ ) (also referred to as "wavenumber") units are used to specify wavelength in the models using the conversion:

$$X(\mu\text{m}) = \frac{10000}{Y(\text{cm}^{-1})}.$$

The  $1.375\text{-}\mu\text{m}$  MODIS is centered at  $1.375\text{ }\mu\text{m}$  and is  $0.03\text{ }\mu\text{m}$  ( $30\text{ nm}$ ) wide, i.e.,  $1.360\text{--}1.390\text{ }\mu\text{m}$ , which is specified as  $7194.24\text{--}7352.94\text{ cm}^{-1}$ . Resolution is not the only difference between the three codes; this will be discussed in more detail below.

The Moderate Resolution Transmittance (MODTRAN) code, developed by the Air Force Research Lab (AFRL), calculates atmospheric transmittance and radiance for frequencies from 0 to  $50,000\text{ cm}^{-1}$  at moderate spectral resolution, primarily  $2\text{ cm}^{-1}$  ( $20\text{ cm}^{-1}$  in the UV) (Berk et al., 1989). The development of the MODTRAN model was motivated by the need for higher spectral resolution than was available in the Low Resolution Transmittance (LOWTRAN7). MODTRAN's capabilities include spherical refractive geometry, solar and lunar source functions, scattering (Rayleigh, Mie, single and multiple), and default atmosphere profiles (gases, aerosols, clouds, fogs, and rain). MODTRAN version 4 release 1 was used for these calculations, and is the most current release.

The Fast Atmospheric Signature Code (FASCODE) is a first principles, line-by-line atmospheric radiance and transmittance code, which was also developed by AFRL (Smith et al., 1978). FASCODE has become the standard benchmark for atmospheric background codes based on band model approaches to radiation transport such as MODTRAN. It is applicable from the visible to long-wavelength infrared. FASCODE is used to calculate atmospheric radiance and path transmission at low altitudes, but can also be used for non-equilibrium high-altitude calculations. FASCODE version 3 was used for these calculations, and is the most current release. FASCODE uses the HITRAN database for information on the spectroscopic transitions of the gases in the atmosphere. The HITRAN database project was started by the Air Force Geophysics Laboratory (AFGL) in the late 1960s and has been continuously updated since then (Rothman, 1998).

The MODTRAN and FASCODE models share some common capabilities (and in some cases source code) for spherical refractive geometry, scattering (Rayleigh, Mie, single and multiple), and default atmosphere profiles. However, the current release of the FASCODE model does not contain a solar source as MODTRAN does, so a direct calculation of the scattering of reflected solar light off the cirrus cloud cannot be performed. This limits the comparison to transmission only.

The geometry used in comparing FASCODE and MODTRAN, which is identical to the geometry used by Gao (1995), is illustrated in Figure 3. The transmission of the atmosphere as a function of wavelength was calculated along the incoming light path from the sun to a point in the atmosphere at an altitude  $z$ , and then from that point back to space. These transmission values are shown in Figures 4–7.

The rationale for using this model geometry is two fold. The model geometry was developed by Gao to support the band selection for the MODIS sensor, and documented in the peer-reviewed literature. This band has been successfully used for operational cirrus detection, providing a sanity check for the model physics. Secondly, as mentioned above, the FASCODE model does not contain a solar source as MODTRAN does, so a direct calculation of scattering of reflected solar light off the cirrus cloud cannot be performed.

A useful metric to compare the model calculations is the average transmission over the band. Two reference altitudes ( $z = 6$  and  $10$  km) and two reference bands ( $1.372\text{--}1.382\mu\text{m}$  and  $1.373\text{--}1.376\mu\text{m}$ ) along with the MODIS band were chosen for comparison. The average transmission across these bands was calculated and tabulated in Tables 1 and 2.

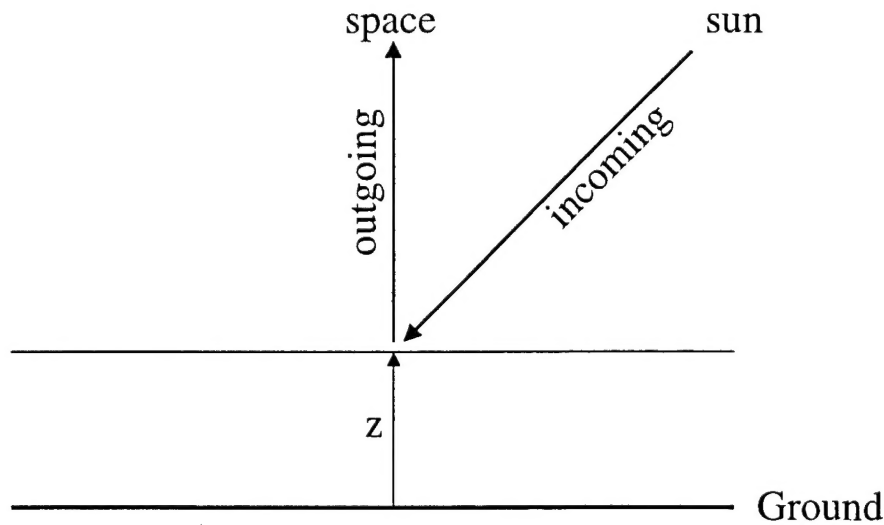


Figure 3. Geometry used in the transmission calculation. The transmission of the atmosphere is calculated from the top of the atmosphere to an altitude  $Z$  at a  $45^\circ$  zenith angle, then back to space at a  $0^\circ$  zenith angle.

Table 1. Band Averaged Transmission for  $Z = 6$  km for the Geometry from Figure 3

Band	MODTRAN MLS	FASCODE MLS	MODTRAN SAW	FASCODE SAW
MODIS	0.1699	0.2222	0.5692	0.6400
$1.372\text{--}1.382\mu\text{m}$	0.2357	0.3031	0.6400	0.6996
$1.373\text{--}1.376\mu\text{m}$	0.2649	0.3474	0.7069	0.7548

Table 2. Band Averaged Transmission for  $Z = 10$  km for the Geometry from Figure 3

Band	MODTRAN MLS	FASCODE MLS	MODTRAN SAW	FASCODE SAW
MODIS	0.7328	0.7875	0.9097	0.9307
1.372-1.382 $\mu\text{m}$	0.7824	0.8243	0.9322	0.9446
1.373-1.376 $\mu\text{m}$	0.8335	0.8626	0.9552	0.9596

### 3. Discussion

As the data in Tables 1 and 2 show, there are significant differences in the band-averaged transmission values calculated by FASCODE and MODTRAN. MODTRAN consistently underestimates the transmission for both altitudes and model atmospheres in all three bands. Figures 4–7 clearly show that the resolution of MODTRAN is not high enough to completely model the spectral structure in this wavelength region. The band-averaged transmissions differ by up to 50% for the MODIS band MLS atmosphere case. This error is comparable to the transmission from the ground to space for the SAW atmosphere.

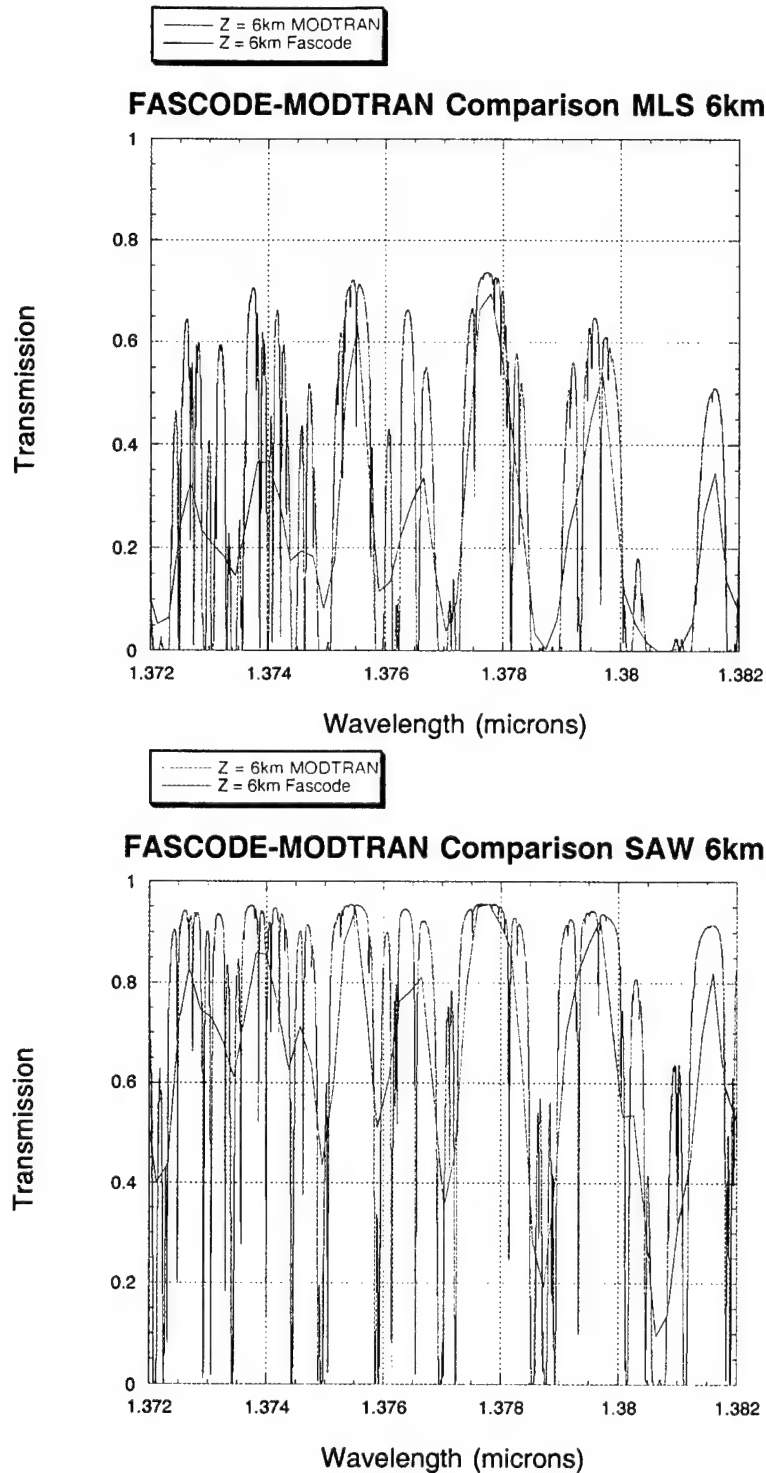


Figure 4. Comparison of the calculated transmission from FASCODE and MODTRAN for the 1.372–1.382  $\mu\text{m}$  band for the Mid-Latitude-Summer (MLS) and Sub-Arctic-Winter (SAW) atmosphere models for a 6-km cloud height.

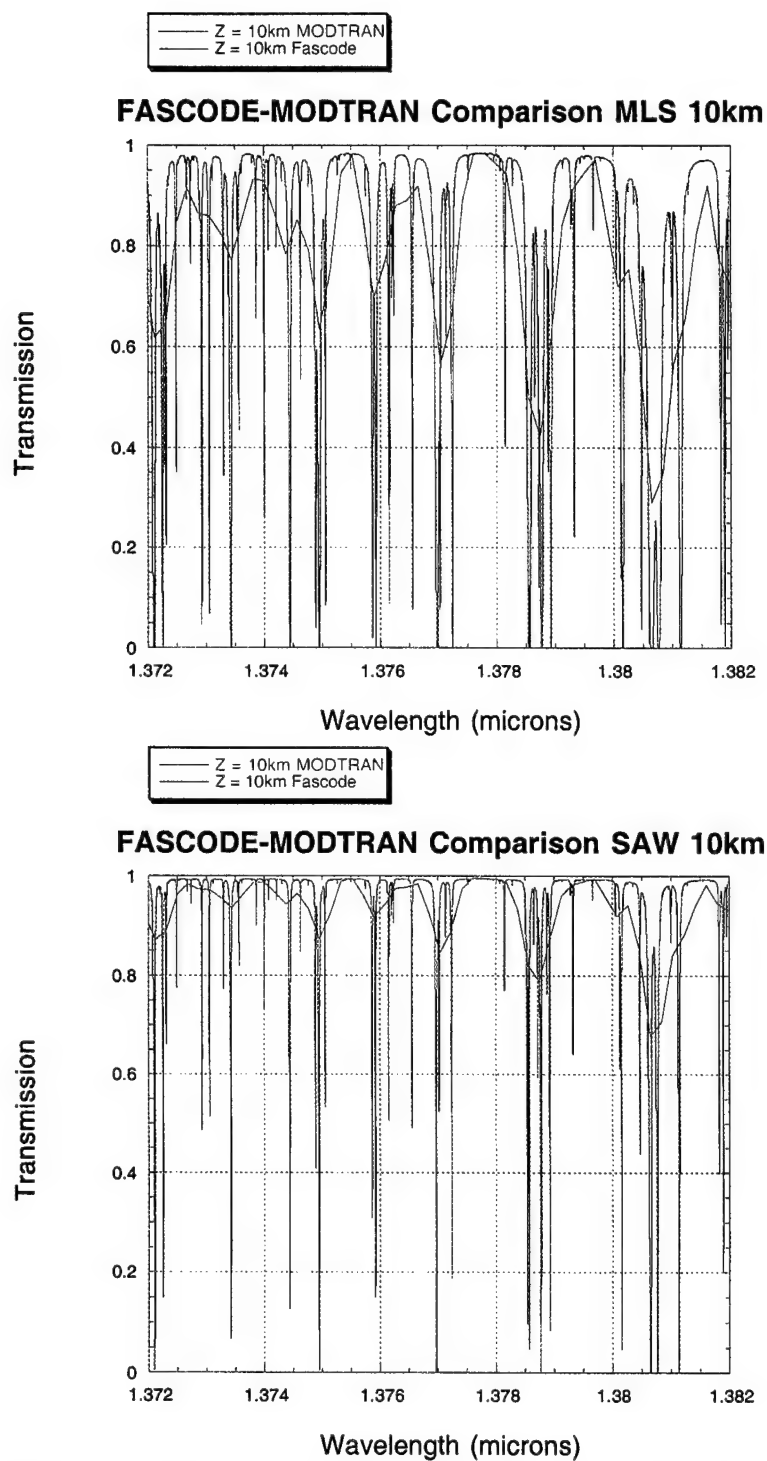


Figure 5. Comparison of the calculated transmission from FASCODE and MODTRAN for the 1.372–1.382  $\mu\text{m}$  band for the Mid-Latitude-Summer (MLS) and Sub-Arctic-Winter (SAW) atmosphere models for a 10-km cloud height.

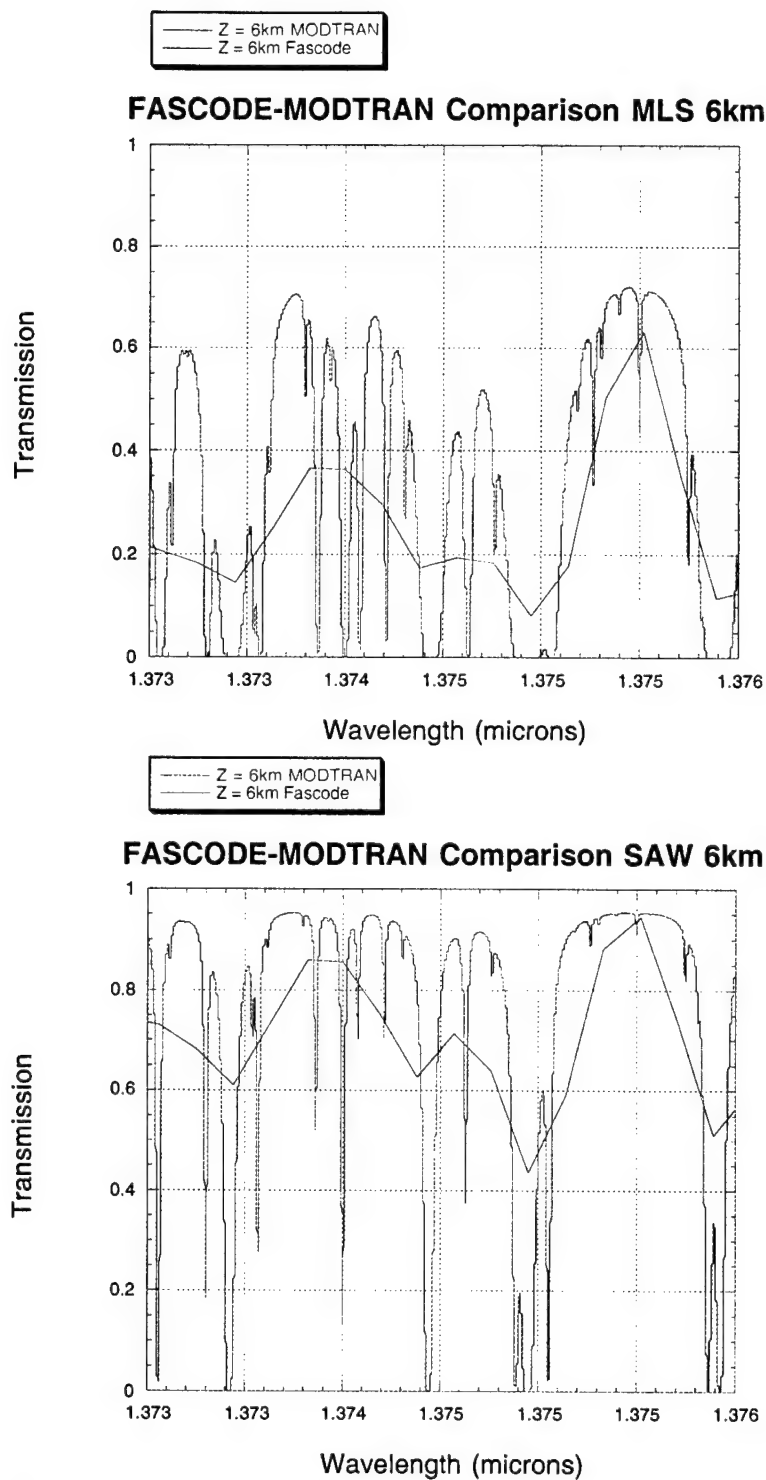


Figure 6. Comparison of the calculated transmission from FASCODE and MODTRAN for the 1.373–1.376  $\mu\text{m}$  band for the Mid-Latitude-Summer (MLS) and Sub-Arctic-Winter (SAW) atmosphere models for a 6-km cloud height.

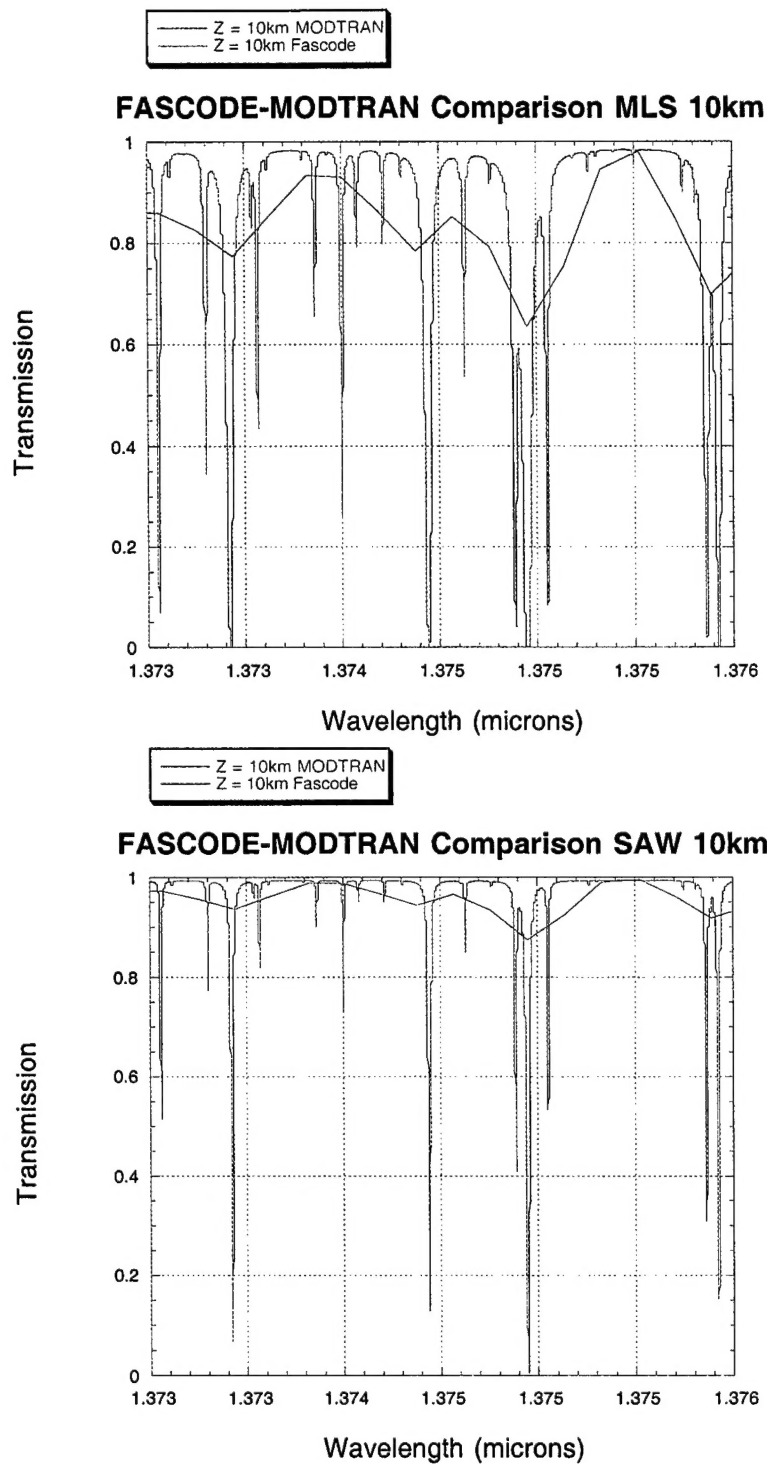


Figure 7. Comparison of the calculated transmission from FASCODE and MODTRAN for the 1.373–1.376  $\mu\text{m}$  band for the Mid-Latitude-Summer (MLS) and Sub-Arctic-Winter (SAW) atmosphere models for a 10-km cloud height.

#### **4. Conclusions**

The results of the simulation are consistent with the work of Gao (1993) for the MODIS band selection, indicating that the physics of the models is sound. MODTRAN's spectral resolution is not high enough to completely model the spectral structure in this band, as compared to FASCODE. The comparison of the band-average transmission yields values that are significantly different between the two models.

The motivation for this analysis was to answer the question: Is MODTRAN resolution sufficient to fully characterize this detection approach, or is the higher spectral resolution of FASCODE required? The answer is that the current release of MODTRAN does not have sufficient spectral resolution to model the spectral structure in this band. The FASCODE model does have the resolution to model this band. The FASCODE model does not have a solar source as MODTRAN does, however, so applying FASCODE to this analysis will require more involved modeling.

## References

- Berk, L. S. Bernstein, and D. C. Robertson, MODTRAN: A Moderate Resolution Model for LOWTRAN 7 (1989), Air Force Geophysics Laboratory Technical Report GL-TR-89-0122, Hanscom AFB, MA.
- Gao, B.-C., & Kaufman, Y. J. (1995). Selection of the 1.375  $\mu\text{m}$  MODIS channel for remote sensing of cirrus clouds and stratospheric aerosols from space. *Journal of the Atmospheric Sciences*, **52**(23), 4231–4237.
- Gao, B.-C., Goetz, A. F. H., and Wiscombe, W. J. (1993). Cirrus cloud detection from airborne imaging spectrometer data using the 1.38 micron water vapor band. *Geophysical Research Letters*, **20**(4), 301–304.
- Gao, B.-C., Kaufman, Y. J., Han, W., and Wiscombe, W. J. (1998). Correction of thin cirrus path radiance in the 0.4–1.0  $\mu\text{m}$  spectral region using the sensitive 1.375- $\mu\text{m}$  cirrus detecting channel. *Journal of Geophysical Research-Atmospheres*, **103**, 32169–32176.
- Rothman, L. S., C. P. Rinsland, A. Goldman, S. T. Massie, D. P. Edwards, J.-M. Flaud, A. Perrin, C. Camy-Peyret, V. Dana, J.-Y. Mandin, J. Schroeder, A. McCann, R. R. Gamache, R. B. Wattson, K. Yoshino, K. V. Chance, K. W. Jucks, L. R. Brown, V. Nemtchinov, and P. Varanasi, (1998). The HITRAN Molecular Spectroscopic Database and HAWKS (HITRAN Atmospheric Workstation): 1996 Edition, *Journal of Quantitative Spectroscopy and Radiative Transfer*, **60**, 665–710.
- Smith, H. J. P., D. J. Dube, M. E. Gardner, S. A. Clough, F. X. Kneizys, and L. S. Rothman, FASCODE- Fast Atmospheric Signature Code (Spectral Transmittance and Radiance) (1978), Air Force Geophysics Laboratory Technical Report AFGL-TR-78-0081, Hanscom AFB, MA.

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